THREE-DIMENSIONAL STRUCTURE FORMING METHOD

This application claims a benefit of priority based on Japanese Patent Application No. 2003-014050, filed on January 22, 2003, which is hereby incorporated by reference herein in its entirety as if fully set forth herein.

BACKGROUND OF THE INVENTION

The present invention relates generally to three-dimensional structure forming method, and more particularly to a three-dimensional structure forming method that forms a three-dimensional structure on thick photosensitive resin.

Recent demands on smaller and lower profile electronic devices have been increasingly demanded finer semiconductor devices to be mounted onto these electronic devices, and a critical dimension has become smaller than 0.15 μm. For this requirement, various proposals have been made to improve resolving power of a projection exposure apparatus.

The resolution improves effectively with increased numerical aperture ("NA") of the projection optical system or higher NA and a shortened wavelength of an exposure light source. Therefore, exposure light sources have recently been in transition from KrF

excimer laser (with a wavelength of approximately 248 nm) to ArF excimer laser (with a wavelength of approximately 193 nm), and F_2 excimer laser (with a wavelength of approximately 157 nm) have been almost reduced to practice.

The projection optical system is subject to chromatic aberration that deteriorates imaging performance because a glass material has different indexes of refraction according to light wavelengths. Therefore, a projection exposure apparatus that uses KrF excimer laser as an exposure light source narrows its band to emit a single beam. A projection exposure apparatus that uses ArF excimer laser as an exposure light source employs for achromatism two types of glass materials of quartz (SiO_2) and calcium fluoride (CaF_2) for an optical system.

However, F_2 laser for use with an exposure light source limits the light transmitting glass material. Currently, CaF_2, magnesium fluoride (MgF_2), lithium fluoride (LiF), etc. are those glass materials that provide desired transmittance, but only CaF_2 is viable to a glass material which provides necessary uniformity and a large aperture of crystal to an optical system in the projection optical system. Therefore, the achromatism is not available through two kinds of glass materials, unlike the projection exposure apparatus that uses ArF excimer laser as an exposure light source.

Accordingly, there has been proposed a projection optical system that uses for achromatism a catadioptric system including a mirror as well as lenses (see, for example, Japanese Laid-Open Patent Application No. 2001-228401). Such a projection optical system requires the mirror not to shield the light, and thus typically utilizes an arc imaging area having a certain height from the optical axis.

A projection optical system that projects a pattern on a mask (or a reticle) onto a substrate that applies photosensitive agent, through a projection optical system that forms an arc imaging area, needs an illumination apparatus for illuminating a mask with an arc illumination area. Typically, a rectangular slit 1000 shown in FIG. 14 is illuminated, and an arc opening 1100 and a light shielding part 1200 take out an arc illumination area. Here, FIG. 14 is a schematic plane view showing one example of the slit 1000 for taking the arc illumination area out of the rectangular illumination area.

However, in taking the arc illumination area out of the rectangular illumination area, the slit shields light and lowers illumination efficiency, and cannot obtain high light intensity on the photosensitive substrate. As the light intensity lowers on the photosensitive substrate, the exposure time becomes long and the circuit-pattern transfer per unit time or

throughput lowers. Therefore, the high light intensity is necessary on the photosensitive substrate.

For enhanced light intensity on the photosensitive substrate, there have been provided a method that uses an optical fiber (see, for example, Japanese Laid-Open Patent Publication No. 5-68846), and a method that uses an arc fly-eye lens that has an arc outline of an element lens (see, for example, Japanese Laid-Open Patent Publication No. 62-115718). However, a method that uses an optical fiber has a practical difficulty because it cannot sufficiently make light uniform through the optical fiber, and no optical fiber can handle with a wavelength of 157 nm.

On the other hand, it is tremendously arduous to manufacture the arc fly-eye lens by processing rod lenses and cutting each outline into an arc shape. In addition, the manufacture tends to have a big process error. As a consequence, the arc fly-eye lens becomes expensive, and the method that uses the arc fly-eye lens has also a practical difficulty because it accumulates process errors when piling up respective element lenses, and deteriorates the entire lens performance. Accordingly, there has recently been proposed a method for processing a micro lens array with the photolithography technology. In particular, a method for making the arc fly-eye lens with the micro lens array has attracted attentions.

The photolithography technology can relatively inexpensively form an arc fly-eye lens from a micro lens array, with a reduced processing error. This is because the error results only from an alignment error of an exposure apparatus, and the error does not accumulate because element lens are not piled up. Therefore, this lens deteriorates the entire performance little.

The photolithography technology transfers a two-dimensional circuit pattern formed by a combination of opening and light-shielding parts, onto photosensitive resin or photoresist etc., and does not usually care about a height direction of the circuit pattern or a three-dimensional shape. There has been provided a method that controls a shape in the height direction by partial exposure-amount adjustments, and forms a three-dimensional shape on the photoresist (see, for example, Japanese Laid-Open Patent Application No. 63-289817). Moreover, there has been proposed a method that etches an optical element with three-dimensional photoresist and manufactures a three-dimensional optical element (see, for example, Japanese Laid-Open Patent Application No. 2002-287370).

The micromechanics, such as a biochip, and an optical element, such as a micro lens array have recently required a special surface shape. Even in this case, a surface shape of a three-dimensional

structure is formed by exposing photoresist formed on a substrate, with a mask having a two-dimensional transmittance distribution, and then developing the photoresist.

When the lithography technology forms a three-dimensional structure on the photoresist as photosensitive resin, a thickness of the photosensitive resin determines a height of the three-dimensional structure. The photosensitive resin's thickness and selectivity with the substrate in etching define a transfer of a photoresist's shape onto the substrate through the anisotropic etching, etc. The three-dimensional structure's height needs to range between sub-micron to about several hundreds micron depending upon purposes of use, such as a micro lens array.

Instant applicants have discovered that in forming photosensitive resin with a three-dimensional structure through exposure with a distributed exposure energy amount, a structure shown in FIG. 15 appears on and remarkably roughens the surface, because almost all the parts of photosensitive resin are developed during a formation of the three-dimensional structure. In other words, after photosensitive resin is applied on the substrate, baking follows to remove solvent and this baking generates the Bernard convection. The Bernard convection produces Bernard cells in the photosensitive resin, and the Bernard cells appear on the surface due

to development. Here, the Bernard convection is a thermal convection that induces a pattern called Bernard cells, as a static and horizontal fluid layer is uniformly heated from the bottom, and a difference of temperature between the upper and bottom surfaces reaches a certain extent. Here, FIG. 15 is a schematic plane view showing exemplary Bernard cells generated in the photosensitive resin.

In a method that transfers a three-dimensional structure onto a substrate using etching, it is conceivable to increase an etching selectivity between the photosensitive resin and the substrate, and to form a desired three-dimensional structure even in photosensitive resin having a small film thickness. However, this method would result in a rougher photosensitive resin shape and newly roughens a surface shape.

BRIEF SUMMARY OF THE INVENTION

Accordingly, it is an exemplary object of the present invention to provide a three-dimensional structure forming method that can form a three-dimensional structure on thick photosensitive resin without roughening a surface shape.

A three-dimensional structure forming method of one aspect according to the present invention that

forms a three-dimensional structure made of a photosensitive material on a substrate includes the steps of determining a film thickness of the photosensitive material necessary to form the desired three-dimensional structure, comparing a predetermined maximum film thickness with the film thickness determined by the determining step, and applying, when the film thickness determined by the determining step is greater than the predetermined maximum film thickness, the photosensitive material within the maximum film thickness plural times until the photosensitive material has the film thickness on the substrate.

A three-dimensional structure forming method of another aspect according to the present invention that forms a three-dimensional structure made of a photosensitive material on a substrate includes the steps of applying onto the substrate photosensitive material with a first film thickness within a preset maximum film thickness, and applying onto the photosensitive material with the first film thickness applied onto the substrate, the photosensitive material with a second film thickness within the maximum film thickness.

A three-dimensional structure forming method that forms a three-dimensional structure made of a photosensitive material on a substrate includes the

steps of repetitively applying and baking a photosensitive material, and forming the photosensitive material with a predetermined thickness on the substrate through overlapping applications.

The above method may further include the steps of exposing, with light having an energy distribution corresponding to the desired three-dimensional structure, the photosensitive material applied by the applying step, and developing the photosensitive material that has been exposed. The method may further include the step of etching the substrate using the photosensitive material that has been exposed.

The substrate is, for example, an optical element or a mold. The photosensitive material is made, for example, of novolac resin. The applying step may apply the photosensitive material through a solvent, and the solvent may be propylene glycol monomethyl ether acetate. The maximum film thickness may be equal to or smaller than 12 μm.

The film thickness of the photosensitive material necessary to form the desired three-dimensional structure may be equal to or greater than 12 μm.

An optical element, a biochip, an optical system that includes the optical element, or an exposure apparatus that includes the optical system, manufactured by the above three-dimensional structure forming method also constitutes another aspect of the

present invention. The optical element may be a lens array that forms plural lenses on an array, and the plural lenses may have a shape of a hexagon, an arc, or a rectangle. The shape may have a width between 12 μm and 2 mm.

A device fabricating method as still another aspect of the present invention includes the steps of using the above exposure apparatus to expose the above object, and performing a predetermined process for the object projected and exposed as above. Claims for a device fabricating method for performing operations similar to that of the above exposure apparatus cover devices as intermediate and final products. Such devices include semiconductor chips like an LSI and VLSI, CCDs, LCDs, magnetic sensors, thin film magnetic heads, and the like.

Other objects and further features of the present invention will become readily apparent from the following description of the preferred embodiments with reference to accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a flowchart for explaining a three-dimensional structure method as one aspect according to the present invention.

FIG. 2 is a schematic sectional view showing a substrate for each manufacture process of a first embodiment.

FIG. 3 is a schematic sectional view showing a substrate for each manufacture process of a comparative example.

FIG. 4 is a schematic sectional view showing a substrate for each manufacture process of a second embodiment.

FIG. 5 is a schematic sectional view showing a substrate for each manufacture process of a third embodiment.

FIG. 6 is a schematic plane view showing a hexagonal micro lens array.

FIG. 7 is a schematic perspective view showing a cylindrical lens.

FIG. 8 is a schematic structure of one example that incorporates a multichannel biosensor with a multifunctional small system, such as a Lab-on-Chip.

FIG. 9 is a schematic plane view of an arc fly-eye lens.

FIG. 10 is a sectional view taken along a line A-A′ of the arc fly-eye lens shown in FIG. 9.

FIG. 11 is a schematic structure of an exemplary exposure apparatus of one aspect according to the present invention.

FIG. 12 is a flowchart for explaining how to fabricate devices (such as semiconductor chips such as ICs and LSIs, LCDs, CCDs, and the like).

FIG. 13 is a flowchart for step 4 that is a wafer process shown in FIG. 12.

FIG. 14 is a schematic plane view showing an exemplary slit for taking an arc illumination area out of a rectangular illumination area.

FIG. 15 is a schematic plane view showing exemplary Bernard cell generated in photosensitive resin.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

First, the instant inventors have reviewed a size of an arc fly-eye lens 400 shown in FIGs. 9 and 10 necessary for a recent projection exposure apparatus that uses, for example, F_2 laser as an exposure light source. Referring to FIGs. 9 and 10, the arc fly-eye lens 400 includes plural element lenses 410 arranged in an array. Here, FIG. 9 is a schematic plane view of the arc fly-eye lens 400, and FIG. 10 is a sectional view taken along line A-A' of the arc fly-eye lens 400 shown in FIG. 9.

In the recent projection exposure apparatus, a wafer has an illumination area of 26 x 8 mm, and a projection optical system has a NA of about 0.8 to

about 0.95. Therefore, the arc fly-eye lens 400 needs an outline Φ of 100 to 160 mm. The excessively small element lens 410 of the arc fly-eye lens 400 would cause interference fringes on the illumination surface, and result in a non-uniform exposure amount on the wafer. The excessively large element lens 410 would result in a discrete secondary light source and deteriorate resolution of a pattern image formed on the wafer.

Therefore, each element lens 410 in the arc fly-eye lens 400 needs to restrict its size, for example, determines a minimum pitch so that the illumination area includes 10 interference fringes to mitigate non-uniform exposure amount.

The outline Φ of the fly-eye lens 400 corresponds to $\sigma = 1.0$ in which the NA of the projection optical system is equal to that of the illumination optical system. Equation 1 below defines a pitch p of the interference fringes, where λ is a wavelength of light, α is the NA of the projection optical system, and d is a pitch between the element lenses:

$$p = \lambda \times \Phi / (2d \times \alpha) \tag{1}$$

Equation 2 below defines the number of interference fringes Y in the illumination area, where X is a width of the illumination area:

$$Y = X / p = (2 \times d \times X \times \alpha) / (\lambda \times \Phi) \tag{2}$$

Equation 3 below the pitch d of the element lenses, where λ = 157 nm, Φ = 100 mm, α = 0.80, X = 8 mm, the number of interference fringes Y is greater than 10:

$$d \geq 10 \times 0.000157 \times 100 / (2 \times 8 \times 0.80) \qquad (3)$$

Therefore, the element lenses 410 should maintain the pitch d greater than 12 μm.

A discrete secondary light source that does not deteriorate the imaging performance provides the maximum pitch of the element lens 410. Although the influence of the discrete secondary light source is not strictly quantified, ten or more element lenses 410 in each direction empirically provide good imaging performance. The outline Φ of 100 mm of the fly-eye lens corresponds to σ = 1.0 in which the NA of the projection optical system is equal to that of the illumination optical system. The illumination condition with σ = 0.2, which is referred to as small σ having high coherence, uses in the area of the outline Φ of 20 mm. Therefore, the element lenses 410 should maintain the pitch equal to or smaller than 2 mm for ten or more element lenses in each direction.

It is thus discovered that the element lenses 410 should maintain the pitch between 12 μm and 2 mm in the arc fly-eye lens 400 used for the recent projection exposure apparatus.

The arc fly-eye lens 400 produced by the photolithography technology requires a optimal

thickness of the element lens 410 in view of its pitch and curvature. This requirement needs the thick photosensitive resin formed on the substrate.

However, the usual photolithography technology does not care about a height of the transferred pattern, and the usual photosensitive resin is 1 μm or smaller thick. In order to form thick photosensitive resin through one application, it is conceivable to adjust viscosity by changing a ratio with a solvent, and the number of revolutions at the coating time. However, this would cause Bernard cells in the photosensitive resin, as discussed above.

In providing a three-dimensional structure forming method that forms a three-dimensional structure using thick photosensitive resin without roughening a surface shape, the instant inventors have discovered, as a result of eager researches of a fundamental generation of Bernard cells, that a film thickness equal to or smaller than 12 μm of photoresist (photosensitive resin) after baking can reduce a possibility of a generation of the Bernard cells.

A description will now be given of a three-dimensional structure forming method as one aspect according to the present invention, with reference to accompanying drawings. FIG. 1 is a flowchart for explaining a three-dimensional structure forming method 100 of one aspect according to the present invention.

The inventive three-dimensional structure forming method 100 is a method for forming photosensitive resin with a desired three-dimensional structure on the substrate, and is suitable, for example, for an optical element and a biochip, such as a micro lens array, a hexagonal fly-eye lens, and an arc fly-eye lens.

Referring to FIG. 1, a necessary film thickness of photosensitive resin is first determined to form a desired three-dimensional structure (Step 102). Next, a determined film thickness and a preset maximum film thickness are compared with each other (Step 104). When the film thickness determined by Step 102 is greater than the set maximum film thickness, the procedure is repeated which includes the steps of applying the photosensitive resin within the maximum film thickness, and baking the resin until the photosensitive resin on the substrate reaches the film thickness determined by the Step 102 (Step 106). In other words, the maximum film thickness is set to be a thickness that does not cause Bernard cells (for example, 12 μm or smaller). When the necessary film thickness of the photosensitive resin to form a desired three-dimensional structure is greater than the maximum film thickness, a set of applying and baking steps is repeated several times so as to form a necessary film thickness on the substrate with reduced or eliminated generation of Bernard cells. When the film thickness

determined by the Step 102 is smaller than the maximum film thickness, photosensitive resin with the necessary film thickness is applied once on the substrate and then baked (Step 108).

After the photosensitive resin application(s) with necessary film thickness onto the substrate ends, exposure follows with light having an energy distribution corresponding to a desired three-dimensional structure (Step 110) and the exposed photosensitive resin is developed (Step 112). Thereby, photosensitive resin having a desired three-dimensional structure is formed on the substrate. Although the desired three-dimensional structure may partially develop the photosensitive resin, photosensitive resin with a highly precise three-dimensional structure is formed with few Bernard cells in the photosensitive resin or few roughened surface shape, since the photosensitive resin is applied onto the substrate within the maximum film thickness.

In the above procedure, it is efficient to repeat an application of photosensitive resin with almost the same thickness for plural applications.

The desired three-dimensional structure can be transferred on the substrate by etching the substrate that has formed the photosensitive resin with a desired three-dimensional structure.

The instant inventors have conducted the above three-dimensional structure forming method 100 with different process conditions, such as the desired three-dimensional structure and substrate.

FIRST EMBODIMENT

FIG. 2 is a schematic sectional view showing a substrate in each manufacture process in a first embodiment. A substrate 10 is a UV-viable synthetic quartz substrate, in particular, F-doped quartz or calcium fluoride as an optical element for F_2 laser. Resist 12a as photosensitive resin of AZ-P4620 (Clariant Co. viscosity 400 cSt novolac resin, solvent: propylene glycol monomethyl ether acetate ("PGMEA")) was formed with a film thickness of 10 μm on the substrate 10 with a coater. Resist 12b with a film thickness of 10 μm was formed under the same condition, and resist 12 with a total film thickness of 20 μm was formed (see FIG. 2A). The resists 12a and 12b did not differ in resist characteristic, and could be treated as one layer of resist.

Exposure followed with a mask 14 having a transmittance distribution designed to form the desired three-dimensional structure (see FIG. 2B). No Bernard cells occurred in the photosensitive resin after a development with dedicated developer, and the photosensitive resin 16 with a desired three-

dimensional structure was formed on the substrate 10 (see FIG. 2C).

Depending upon a wavelength for use with an optical element, *e.g.*, He-Ne laser with a wavelength of 633 nm, photosensitive resin 16 having the desired three-dimensional structure can be used as it is for the optical element.

The instant embodiment used a dry etching apparatus to conduct anisotropic etching with a selectivity of 1 and transfer a shape of the photosensitive resin 16 onto the substrate 10 (see FIG. 2D). The desired optical element could be thus manufactured without forming Bernard cells that roughened the surface shape.

COMPARATIVE EXAMPLE

FIG. 3 is a schematic sectional view showing a substrate in each manufacture process in a comparative example. A coater formed resist 22 as photosensitive resin of AZ-P4903 (Clariant Co. viscosity 1500 cSt novolac resin, solvent: PGMEA) with a film thickness of 20 μm on the substrate 10 similar to that for the first embodiment, through one application (see FIG. 3A). The resist 22 had a smooth surface at this time.

Exposure followed with a mask 14 similar to that for the first embodiment (see FIG. 3B). Then, a development with dedicated developer followed, and

photosensitive resin 24 with a three-dimensional structure was formed. Bernard cells were formed over a surface and roughened a surface shape.

SECOND EMBODIMENT

FIG. 4 is a schematic sectional view showing a substrate in each manufacture process in a second embodiment. A substrate 30 is a ceramic plate used as a glass mold. The instant embodiment used SiC that could be processed with gas of fluorine and chlorine systems. Ceramics is a low thermal expansion material with good repetitive heating and cooling resistance and suitable for a glass mold. However, it has disadvantages in hard maintenance of surface flatness and hard processability. Noble metal coating could maintain the surface flatness, but the processability has been a major problem along with recently required higher accuracy and complicated shape.

Resist 32a as photosensitive resin of PMER P-LA900PM (Tokyo Ohka Kogyo Co., Ltd., viscosity 900 cSt novolac resin, solvent: PGMEA) was formed with a film thickness of 12 μm on a substrate 30 with a coater. Resists 32b and 32c were formed with a film thickness of 12 μm under the same condition, and resist 32 was formed with a total film thickness of 36 μm (see FIG. 4A). The resists 32a, 32b and 32c did not differ in

resist characteristic, and could be treated as one layer of resist.

Exposure followed with a mask 34 having a transmittance distribution designed to form the desired three-dimensional structure (see FIG. 4B). No Bernard cells occurred in the photosensitive resin after a development with dedicated developer, and the photosensitive resin 36 having a desired three-dimensional structure was formed on the substrate 30 (see FIG. 4C).

The instant embodiment used a dry etching apparatus to conduct anisotropic etching with a selectivity of 1 and transfer a shape of the photosensitive resin 36 onto the substrate 30 (see FIG. 4D). Pt (not shown) was coated on the substrate 30, and glass 38 was molded, as shown in FIG. 4E, with a glass mold (see FIG. 4F). A desired optical element with high temperature molding resistance which could easily process a complicated shape, such as an aspheric surface, could be thus manufactured without forming Bernard cells that roughened the surface shape.

THIRD EMBODIMENT

FIG. 5 is a schematic sectional view showing a substrate in each manufacture process in a third embodiment. This embodiment forms a hexagonal micro lens array on the substrate 10 similar to that for the

first embodiment. Resist 42a as photosensitive resin of AZ-P4620 (Clariant Co. viscosity 400 cSt novolac resin, solvent: PGMEA) was formed with a film thickness of 10 μm on the substrate 10 with a coater. Resist 42b was formed with a film thickness of 10 μm nine times under the same condition, and resist 42 was formed with a total film thickness of 100 μm (see FIG. 5A). The resists 42a and 42b did not differ in resist characteristic, and could be treated as one layer of resist.

Exposure followed with a mask having a transmittance distribution designed to form the hexagonal micro lens array. No Bernard cells occurred in the photosensitive resin after a development with dedicated developer, and the photosensitive resin 46 was formed with a hexagonal micro lens array on the substrate 10 (see FIG. 5B).

The instant embodiment used a dry etching apparatus to conduct anisotropic etching with a selectivity of 1 and transfer a shape of the photosensitive resin 46 onto the substrate 10 (see FIG. 5C). The desired hexagonal micro lens array could be thus manufactured on the photosensitive resin 42 with a film thickness of 100 μm, as shown in FIG. 6, without forming Bernard cells that roughened the surface shape. Here, FIG. 6 is a schematic plane view showing the hexagonal micro lens array.

While the instant embodiment manufactures a micro lens array, a micro mirror array can be manufactured by forming a mirror using a multilayer film of Si and Mo on the substrate 10, onto which the above shape has been transferred. Such a micro mirror array can be used as a reflective integrator in an exposure apparatus that uses EUV light as exposure light.

FOURTH EMBODIMENT

This embodiment forms a cylindrical lens on a substrate similar to that for the first embodiment. Resist as photosensitive resin of SU-85 (Macdermit Co. Ltd., viscosity 290 cSt epoxy resin, solvent: γ-Butyrolactones) was formed with a film thickness of 8 μm on the substrate 10 with a coater. Resist was additionally formed with a film thickness of 8 μm under the same condition, and resist was formed with a total film thickness of 16 μm.

Exposure followed with a mask having a transmittance distribution designed to form a cylindrical lens. No Bernard cells occurred in the photosensitive resin after a development with dedicated developer, and the photosensitive resin was formed with a cylindrical lens shape.

The instant embodiment used a dry etching apparatus to conduct anisotropic etching with a selectivity of 1 and transfer a cylindrical lens shape

of the photosensitive resin onto the substrate. The desired cylindrical lens could be thus manufactured, as shown in FIG. 7, without forming Bernard cells that roughen the surface shape. Here, FIG. 7 is a schematic perspective view of the cylindrical lens.

While the instant embodiment manufactures a cylindrical lens, a cylindrical mirror can be manufactured by forming a mirror using a multilayer film of Si and Mo on the substrate, onto which the above shape has been transferred. Such a cylindrical mirror can be used as a reflective integrator in an exposure apparatus that uses EUV light as exposure light.

FIFTH EMBODIMENT

FIG. 8 is a schematic structure of one example that incorporates a multichannel biosensor into a multifunctional small system 300, such as a Lab-on-a-Chip, wherein FIG. 8A is a schematic plane view and FIG. 8B is a schematic sectional view.

Referring to FIG. 8, solution or gas as an analysis object is introduced into a sensor system through a sample inlet 310, subject to sample separation and extraction in a pretreatment element 320, and guided to a detector part 330.

While the pretreatment may need various functions, such as a mixer / reactor, a filter, and a valve, a

detailed description thereof will be omitted. In addition, the pretreatment may need specific reagent for reaction, and a channel and inlet to introduce this reagent. On the other hand, mechanical equipment, such as a pump, electrical equipment, such as electro-osmosis, etc. can be broadly used to move a sample.

The detector part 330 detects the sample, and wiring of detecting channel 340 takes out data. Sample solution or gas after detections is exhausted from an outlet 350.

The inventive three-dimensional structure forming method forms the above Lab-on-a-Chip with a three-dimensional structure on a substrate similar to that for the first embodiment.

Resist as photosensitive resin of OEBR-1000 (Tokyo Ohka Kogyo Co., Ltd., viscosity 300 cSt poly(methyl methacrylate: PMMA), solvent: ethyl cellosolve acetate) was formed with a film thickness of 10 μm on the substrate with a coater. Resist was additionally formed twice with a film thickness of 10 μm under the same condition, and resist was formed with a total film thickness of 30 μm.

EB Exposure followed to form a three-dimensional structure shown in FIG. 8. In other words, the dose was changed and the complicated three-dimensional structure was formed as shown in FIG. 8. Exposure that uses far ultraviolet light and a mask can replace for

mass-production. Use of the inventive three-dimensional structure forming method 100 to manufacture the above Lab-on-a-Chip could obtain a high-sensitive and high-performance biosensor without Bernard cells that roughened a surface shape.

Referring now to FIG. 11, a description will be given of an exposure apparatus 500 of one aspect according to the present invention. Here, FIG. 11 is a schematic structure of the exposure apparatus 500 of one aspect according to the present invention. The exposure apparatus 500 includes, as shown in FIG. 11, an illumination apparatus 510, a mask (or reticle) 520, a projection optical system 530, a substrate (or plate) 540, and a stage 545.

The exposure apparatus 500 is a projection exposure apparatus uses, *e.g.*, a step-and-repeat, or step-and-scan manner to expose a pattern formed on the mask 520 onto the substrate 540. Such an exposure apparatus is suitably applicable to a lithography process below submicron or quarter-micron, and a description will be given below of this embodiment exemplarily using a step-and-scan exposure apparatus (which is also called "a scanner"). The step-and-scan manner, as used herein, is an exposure method that exposes a mask pattern onto a wafer by continuously scanning the wafer relative to the mask, and by moving, after a shot of exposure, the wafer stepwise to the

next exposure area to be shot. The step-and-repeat manner is another mode of exposure method that moves a wafer stepwise to an exposure area for the next shot every shot of cell projection onto the wafer.

The illumination apparatus 510, which illuminates the mask 520 that forms a circuit pattern to be transferred, includes a light source section 512 and an illumination optical system 514.

The light source section 512 uses F_2 laser with a wavelength of about 157 nm as a light source in the instant embodiment. The present invention does not limit a kind of the light source section 512 to F_2 laser, but can use for the light source section 512 excimer lasers and extreme ultraviolet with a wavelength about 5 to 20 nm.

The illumination optical system 514 is an optical system that illuminates the mask 520, and includes a darkening means 514a, beam swing means 514b, a fly-eye lens 514c, a condenser lens 514d, a fly-eye lens 514e, a condenser lens 514f, an effective light source forming stop 514g, a zoom relay lens 514h, a fly-eye lens 514i, a condenser lens 514j, a masking blade 514k, a masking imaging lens 514l.

The darkening means 514a controls the light intensity on the illuminated surface. In use of a pulse light source, such as F_2 laser, for the light source section 512, an exposure amount scatters due to

scattering outputs among laser pulses. Therefore, it is necessary to reduce the scattering exposure amount by considering the number of exposure pulses to be the number of predetermined pulses or greater and by averaging scattering pulses. When the photosensitive agent has high sensitivity, the darkening means 514a darkens light to reduce the light intensity and expose with the number of predetermined pulses or greater.

The beam swing means 514b swings a beam from the light source section 512, and swings the speckle distribution to average speckles over time during exposure. The beam swing method includes a method for rotating an inclined parallel plate, a method for swinging a mirror, a method for rotating a wedge prism, etc. The instant embodiment uses coherent F_2 laser for the light source in the light source section 512, and thus speckles occur on the illuminated surface. Speckles occur due to non-uniform light intensity and scattering exposure amounts on the illuminated surface, and cause critical dimensions of resolved images from the mask 520 to the substrate 540 to disadvantageously differ according to locations (or deteriorate CD uniformity). Therefore, the beam swing means 514b is provided.

The fly-eye lens 514c forms a secondary light source on an exit surface, and Koehler-illuminates an incident surface of the fly-eye lens 514e through the

condenser lens 514d. A turret arranges plural fly-eye lenses 514c, and can switch the exit NA from the fly-eye lens 514c, thereby changing an irradiation range on an incident surface of the fly-eye lens 514i. This is to avoid light condensing on the exit surface of the fly-eye lens 514i when the zoom relay lens 514h changes a magnification.

The fly-eye lens 514e forms a tertiary light source on an exit surface, and Koehler-illuminates the effective light source forming stop 514g through the condenser lens 514d. A double fly-eye lens structure from the fly-eye lens 514c to condenser lens 514f maintains a light distribution on the effective light source forming stop 514g even when the laser beam changes its profile, and can always form a uniform effective light source.

For example, without a fly-eye lens 514c and the condenser lens 514d, a change of a positional distribution from the laser changes the light intensity distribution on the incident surface of the fly-eye lens 514e and thus the light's angular distribution on the effective light source forming stop 514g. A change of the light's angular distribution shifts the light intensity distribution on the exit surface of the fly-eye lens 514i, which will be described later, and inclines the angular distribution on the substrate 540. When the substrate 540 defocuses, a transfer position

changes (on-axis telecentricity). Therefore, a double fly-eye lens structure is used from the fly-eye lens 514c to condenser lens 514f.

The effective light source forming stop 514 g defines the effective light source that is a light source for illuminating the mask 520. The effective light source usually has a circular shape. On the other hand, the fly-eye lens 514e uses a rectangular fly-eye lens in which its rod lens has a rectangular outline, a hexagonal fly-eye lens in which its rod lens has a hexagonal outline, and a cylindrical lens array that arranges cylindrical lens arrays as element lenses. Therefore, the distribution formed on the effective light source forming stop 514g at the light source section 512 would have a square shape for the rectangular fly-eye lens and cylindrical lens array, and a hexagonal shape for the hexagonal lens array. Therefore, the effective light source forming stop 514g having a circular opening is needed to form a circular effective light source.

The zoom relay lens 514h projects a circular light intensity distribution formed on the effective light source forming stop 514g, onto the incident surface of the fly-eye lens 514i at a predetermined magnification. A size of the light source that illuminates the mask 520 is referred to as a coherent factor, and required to be variable according to a pattern to be transferred

so as to improve performance of the projection optical system 530. Accordingly, a size of the illuminated area on the incident surface of the fly-eye lens 514i is made variable by making variable the magnification of the relay optical system of the zoom relay lens 514h.

The fly-eye lens 514i forms a quaternary light source on an exit surface, and illuminates the masking blade 514k with a uniform light intensity distribution through the condenser lens 514j. The fly-eye lens 514i uses an arc fly-eye lens since the projection optical system 530 has a circular imaging area and the mask 520 should be illuminated with an arc shape. The exposure apparatus 500 is a scanner and can correct non-uniform exposure amount in the perpendicular direction by changing a width of the arc illumination area. For example, it is desirable to switch plural fly-eye lenses 514i having different arc widths arranged on a turret for an adjustment to the arc width.

The masking blade 514k controls an exposure area, and is driven according to a scan area to obtain desired exposure area.

The masking imaging lens 514l projects a light intensity distribution on the masking blade 514k onto the mask 520.

The illumination optical system 514 uses the fly-eye lenses 514c, 514e and 514i formed by the inventive

three-dimensional structure forming method, and maintains desired optical performance.

The mask 520 forms a circuit pattern (or an image) to be transferred and is supported and driven by a mask stage (not shown). The mask 520 is made of a material having high transmittance to a wavelength of 157 nm, such as F-doped quartz and calcium fluoride. Diffracted light from the mask 520 passes through the projection optical system 530, and is projected onto the substrate 540. The mask 520 and the substrate 540 are disposed in an optically conjugate relationship. Since the exposure apparatus 500 of the instant a scanner, a scan of the mask 520 and the substrate 540 at a reduction speed ratio transfers the pattern on the mask 520 onto the object 540.

The projection optical system 530 is a catadioptric optical system that has plural lens and at least one concave mirror. The projection optical system 530 uses lenses and a mirror for achromatism and maintains good imaging performance in arc imaging area.

The substrate 540 is an object to be exposed, such as a wafer and a liquid crystal substrate, and photoresist is applied onto the substrate 540.

The stage 545 supports the substrate 540. The stage 545 can use any structure known in the art, and a detailed description of its structure and operation will be omitted. The stage 545 uses, for example, a

linear motor to move the substrate 540 in X-Y-Z directions. The positions of the stage (not shown) and stage 545 are monitored, for example, by a laser interferometer and the like, so that both are driven at a constant speed ratio.

In exposure, a F_2 laser beam emitted from the light source section 512 Koehler-illuminates the mask 520 through the illumination optical system 514. light that transmits the mask 520 and reflects a mask pattern images on the substrate 540 through the projection optical system 530. The fly-eye lenses 514c, 514e and 514i in the illumination optical system in the exposure apparatus 500 are formed by the inventive three-dimensional structure forming method 100, and can maintain optical performance. In addition, the fly-eye lens 514i can use an arc fly-eye lens, and the substrate 540 can maintain high light intensity on its surface. As a result, higher quality devices, such as semiconductor devices, LCD devices, image-pickup elements (*e.g.*, CCD), and thin-film magnetic heads, than the conventional, can be provided with high throughput and good economic efficiency.

While this embodiment uses F_2 laser as exposure light for the exposure apparatus, an optical element manufactured according to the inventive three-dimensional structure forming method 100 can be used

for such an exposure apparatus as uses X-ray, such as EUV, for exposure light.

Referring to FIGs. 12 and 13, a description will now be given of an embodiment of a device fabrication method using the above mentioned exposure apparatus 500. FIG. 12 is a flowchart for explaining a fabrication of devices (*i.e.*, semiconductor chips such as IC and LSI, LCDs, CCDs, etc.). Here, a description will be given of a fabrication of a semiconductor chip as an example. Step 1 (circuit design) designs a semiconductor device circuit. Step 2 (mask fabrication) forms a mask having a designed circuit pattern. Step 3 (wafer making) manufactures a wafer using materials such as silicon. Step 4 (wafer process), which is referred to as a pretreatment, forms actual circuitry on the wafer through photolithography using the mask and wafer. Step 5 (assembly), which is also referred to as a post-treatment, forms into a semiconductor chip the wafer formed in Step 4 and includes an assembly step (*e.g.*, dicing, bonding), a packaging step (chip sealing), and the like. Step 6 (inspection) performs various tests for the semiconductor device made in Step 5, such as a validity test and a durability test. Through these steps, a semiconductor device is finished and shipped (Step 7).

FIG. 13 is a detailed flowchart of the wafer process in Step 4. Step 11 (oxidation) oxidizes the

wafer's surface. Step 12 (CVD) forms an insulating film on the wafer's surface. Step 13 (electrode formation) forms electrodes on the wafer by vapor disposition and the like. Step 14 (ion implantation) implants ion into the wafer. Step 15 (resist process) applies a photosensitive material onto the wafer. Step 16 (exposure) uses the exposure apparatus 500 to expose a circuit pattern on the mask onto the wafer. Step 17 (development) develops the exposed wafer. Step 18 (etching) etches parts other than a developed resist image. Step 19 (resist stripping) removes disused resist after etching. These steps are repeated, and multilayer circuit patterns are formed on the wafer. This device fabrication method may manufacture higher quality devices than conventional. In this manner, the device fabrication method that uses the exposure apparatus 500 and resultant devices serve as other aspects of the present invention.

Further, the present invention is not limited to these preferred embodiments, and various variations and modifications may be made without departing from the scope of the present invention.

Thus, the present invention can provide a three-dimensional structure forming method that can form a three-dimensional structure on thick photosensitive resin without roughening a surface shape.